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A Stormwater and Nonpoint Source Management Tool

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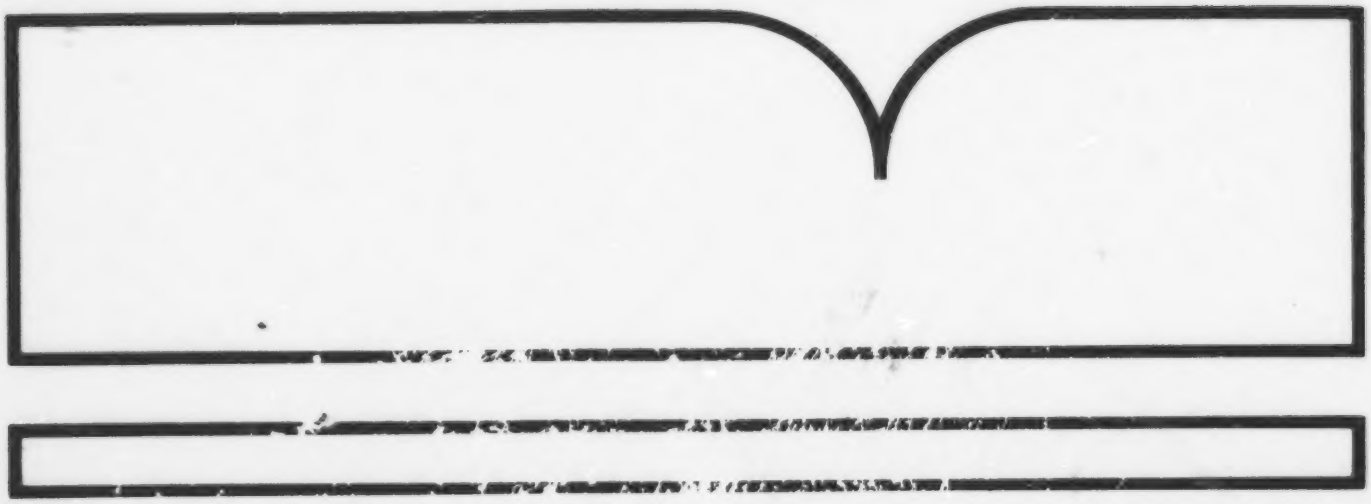

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This report provides a model to be used as an effective water resources management tool during the anticipated urbanization of the Piscataway Creek watershed. It provides the opportunity to assess the nonpoint source pollution and stormwater impacts of planned development, and project future nonpoint source nutrient loads from within the basin to the Potomac River estuary.

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THE PISCATAWAY CREEK WATERSHED MODEL: A STORMWATER AND NONPOINT SOURCE MANAGEMENT TOOL

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INTRODUCTION

The Piscataway Creek Watershed Study was undertaken to develop a prototype nonpoint source water quality management program for the watershed. The watershed currently has a rural character with a few scattered pockets of residential and commercial development. However, due in large part to its proximity to Washington, D.C., a great deal of development is expected to occur over the next two decades. And as development proceeds, the need for stormwater and water quality management is also expected to increase within the watershed. The purpose of the study is threefold: (1) to develop a watershed model as an effective water resources management tool; (2) to assess the nonpoint source pollution and stormwater impacts of planned development; and (3) to project future nonpoint source nutrient loads from within the basin to the Potomac estuary.

Funding for the study was provided with a grant from the U.S. Environmental Protection Agency under the Nationwide Urban Runoff Program (NURP). The watershed analysis is being conducted in conjunction with the Maryland-National Capital Park and Planning Commission, Prince George's County, Maryland.

This paper will focus on a description of the watershed, application of the HSPF model (Hydrocomp,1980), model calibration and verification results, model projections made to date, and remaining work since the study is not yet complete. In addition, a few general comments on the use of the HSPF model will also be presented.

Paper presented at the Stormwater and Water Quality Users Group Meeting, October 18-19, 1982, Ottawa, Ontario, Canada.

DESCRIPTION

The Piscataway watershed is located entirely within Prince George's County, Maryland, and is centered some 15 miles to the southeast of Washington, D.C. (Figure 1). The watershed encompasses an area of 55 square miles, and it drains to the Piscataway embayment, a tidal appendage of the Potomac estuary. The climate is humid and temperate, with average precipitation being about 40 inches per year.

Topographically, the watershed has a well defined valley with elevations ranging between sea level and 250' above sea level. Geomorphologically, the watershed lies within the Atlantic Coastal Plain Province. Soils are principally sandy loams and silt loams derived from the underlying sedimentary materials.

The current land use makeup of the watershed is as follows: residential and commercial development occupy approximately 15 percent of the area; pasture and row crops occupy another 15 percent; and the remainder is principally forest with some areas of open unforested land. Total imperviousness in the watershed is estimated to be 6 percent.

HSPF APPLICATION

The HSPF model is a continuous simulation hydrology and water quality model. HSPF stands for "Hydrologic Simulation Program-Fortran". It represents a non-proprietary version of Hydrocomp's HSP model (Hydrocomp,1977), and it contains the major elements of EPA's Nonpoint Source model (Donigian and Crawford,1976) and Agricultural Runoff model (Donigian and Davis,1978). In brief, the model accomplishes soil moisture accounting, runoff production, sediment and nonpoint source pollution generation, and the routing of water and pollutant loads through a stream channel system.

In applying the model to the Piscataway Creek watershed, four land use types were modeled separately to account for inherent differences in hydrologic and pollutant generation rates. These were forest, a combined pasture and row crop category, open-unforested land, and a developed residential/commercial category. In addition, all of the imperviousness associated with any given land use within the watershed was aggregated together and modeled as a single land use type.

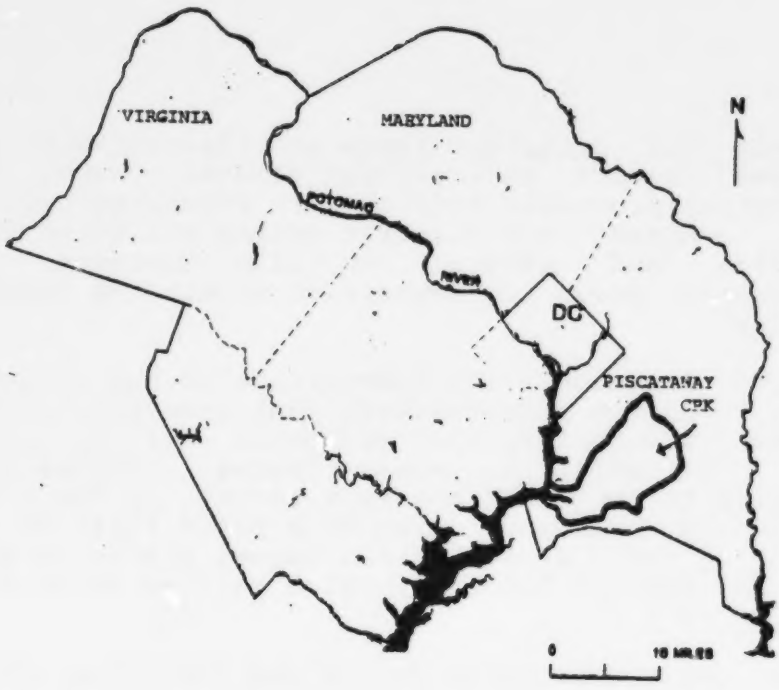

Figure 1. Metropolitan Washington Area and Piscataway Creek Watershed.

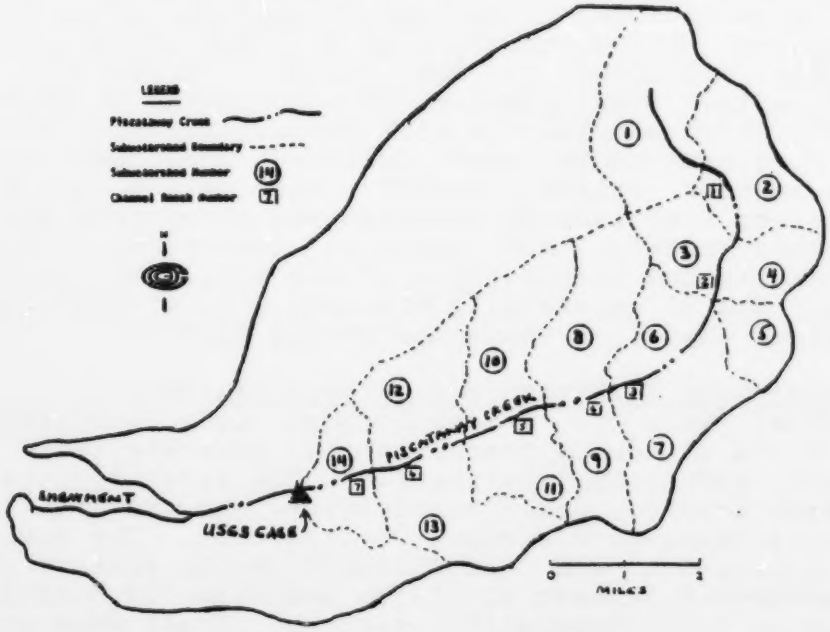

Figure 2. Subwatersheds of Piscataway Creek

Runoff and pollutant loads were delivered to and routed through an idealized channel system. The principal processes modeled were watershed hydrology, sediment and nonpoint source pollution production and removal on land surfaces, and transport, scour and deposition within the channel system.

Figure 2 presents the subdivision of the waterhed into fourteen subwatersheds that generally correspond to tributaries or groups of small tributaries. In addition, seven channel reaches were modeled to represent the main channel of the creek from its headwater area to a point close to its mouth at the U.S. Geological Survey discharge gaging station (GS 01653600) which is also identified on Figure 2.

Mean daily discharge values and individual storm hydrographs were available at this USGS station. Over the sixteen year period of record, mean discharge was approximately 50 cfs, while the peak flow was slightly less than 10,000 cfs. Water quality data was also collected at the same station over an eighteen month period during 1980-81. As part of the EPA NURP study, an automated water quality sampler was installed. The sampler was triggered to collect samples during discrete rises in stage and was shut off when stage fell below pre-storm levels. During the eighteen month monitoring period, thirty flow weighted storm samples were collected in this manner. In addition, 45 baseflow grab samples were collected to augment the storm samples. A wide variety of water quality constituents were analysed including total suspended solids, DO/BOD, particulate and dissolved fractions of nitrogen and phosphorus forms, trace metals, and bacteria indicators. Calibration and verification of the model was confined to the 40 square mile drainage area of Piscataway Creek that lies above the gaging station.

Hydrology Calibration and Verification

Nine years of meteorological data, including a record of hourly precipitation, were available for the hydrology application. The first four years were used for model calibration, and the next five were reserved for model verification. The goal of calibration and verification was to achieve good agreement between simulated and observed discharge using four comparative measures. These were annual runoff, monthly runoff, individual storm hydrographs, and flow duration. Verification results represent application of the calibrated

hydrology parameters without change to the five year verification period.

Figure 3 presents a comparison of simulated versus observed annual runoff for the full nine year period. As shown, annual runoff was simulated well during both the calibration and verification periods. Overall, the difference between simulated and observed runoff for the entire nine year period was less than 5 percent.

A comparison of simulated versus observed monthly runoff volumes for the calibration period is presented in Figure 4. The scatter of points around the one-to-one line is rather close over a large range of runoff volumes. The regression line, which is not shown on the plot, yielded a Pearson correlation coefficient (r^2) of 0.95. Figure 5 provides an example of the ability of the model to reproduce individual storm hydrographs, in this case the observed peak flow event of 1973. The simulated hydrograph is slightly out of phase with the observed flow, but the peak flow rate itself as well as overall storm runoff volume are reproduced well. The fourth measure, flow durations, is compared in Figure 6. The closeness of these curves provides evidence that the distribution of simulated daily values over the full four year calibration period is very similar to the distribution of observed values.

Based upon these results and other plots of individual storm hydrographs, it was decided that the calibrated hydrology parameters were very capable of representing the hydrologic processes occurring within the watershed. A full discussion of the hydrologic calibration and verification including model inputs and data requirements, and a complete discussion of calibration and verification results, is documented in a separate report (Sullivan,et al,1982).

Sediment and Water Quality Calibration

Because of the relatively small amount of sediment (total suspended solids) and water quality data available for the watershed, it was not practical to isolate a separate verification period for this part of the model application. Therefore, all of the available data was used in calibration, with the results of the calibration standing on their own merit. A great deal of specific local information on land use/runoff quality relationships (NVPDC and VPI&SU,1978) and nonpoint pollution loading factors (Hartigan,et al,1982) was drawn upon in this portion of the model application.

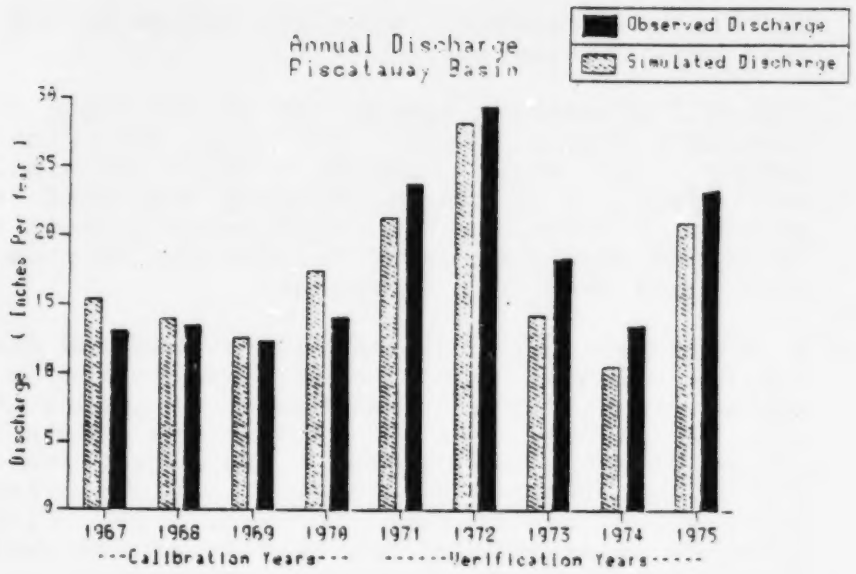

Figure 3. Comparison of Simulated and Observed Annual Runoff

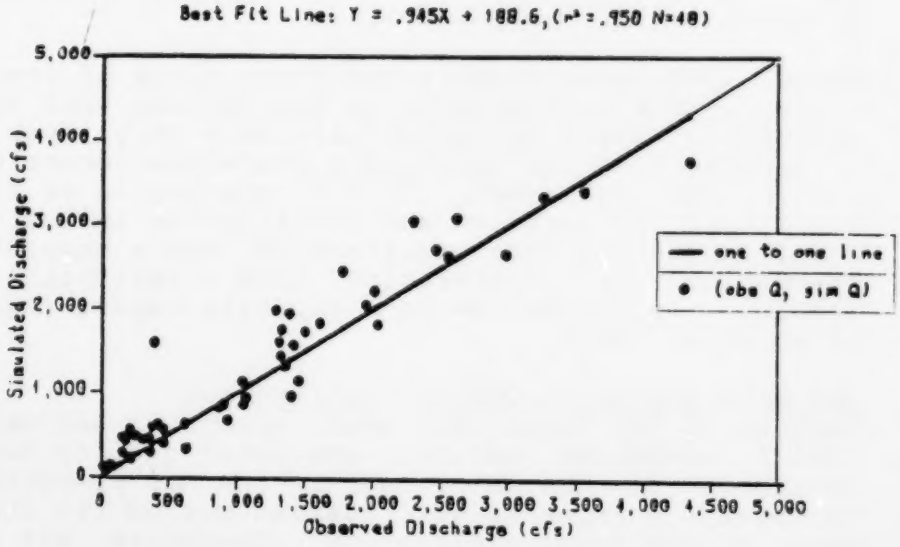

Figure 4. Comparison of Simulated and Observed Monthly Runoff (cfsd) for Calibration Period

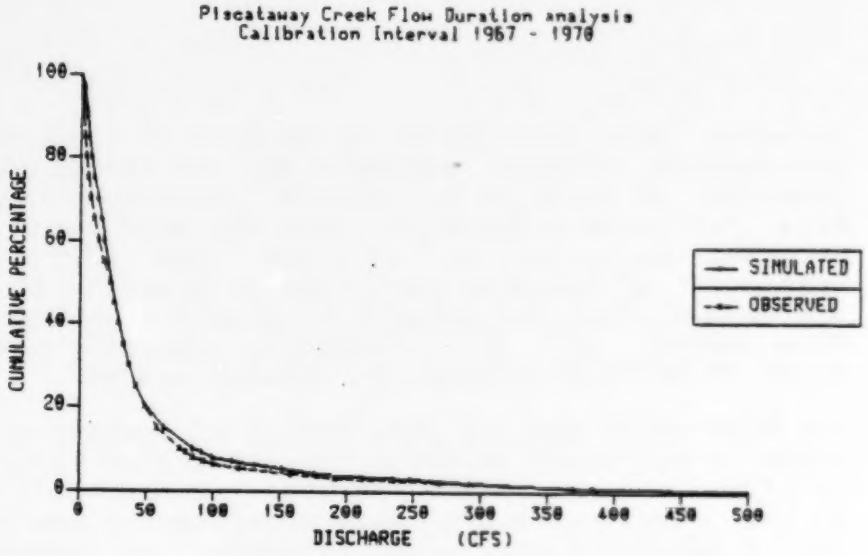

Figure 5. Flow Duration Analysis

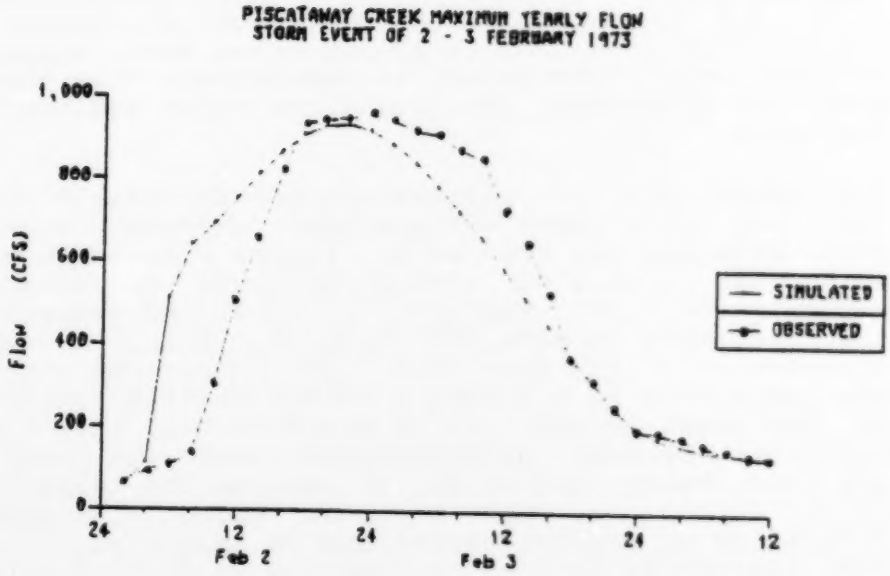

Figure 6. Comparison of Storm Hydrographs

Sediment was modeled first because of the close association between sediment and the particulate fraction of nonpoint pollutants. Principal sediment processes modeled included the production of detached particles on pervious land surfaces; transport of detached particles in overland flow; the accumulation and washoff of sediment on impervous areas; and the transport, deposition and scour of sediment within the channel system.

The NURP water quality data indicated a sharp contrast in suspended sediment concentrations between baseflow and stormflow periods. Concentrations during baseflow periods were consistently low and had a mean of 6 mg/l. During storm flow periods, suspended sediment concentrations varied from slightly over 100 mg/l to 2000 mg/l, with a mean of 500 mg/l.

The results of the sediment calibration were quite encouraging. Simulated and observed storm sediment yields in tons are shown plotted along a line of one to one correspondence on Figure 7. Fairly close agreement was achieved over a wide range of storm events with sediment yields varying over three orders of magnitude. A slight bias toward undersimulation is obvious in the plot. However, given the complexity of the processes, and uncertainty with model inputs and observed data, these results were considered to demonstrate that the model was adequately simulating the major sediment processes.

The water quality calibration was incomplete at the time this paper was prepared. However, some good progress had been made. Figure 8 presents a plot of simulated versus observed dissolved oxygen. As shown, the major seasonal and temperature related trends are captured. Fairly close agreement is achieved at all concentrations with the exception of a tendency toward oversimulation at the lower levels. It is probable that this is occurring because phytoplankton growth and death are not being simulated, or because the temperature inputs are not accurate enough for the simulation of diurnal variations in concentration. Some additional work to improve the ability of the model to simulate low summertime dissolved oxygen concentrations is underway, and this is not perceived as a continuing problem.

Baseflow nitrate concentrations are presented in Figure 9. Again there is fairly close agreement across a broad range of concentrations, but with the tendency toward oversimulation of low summer-

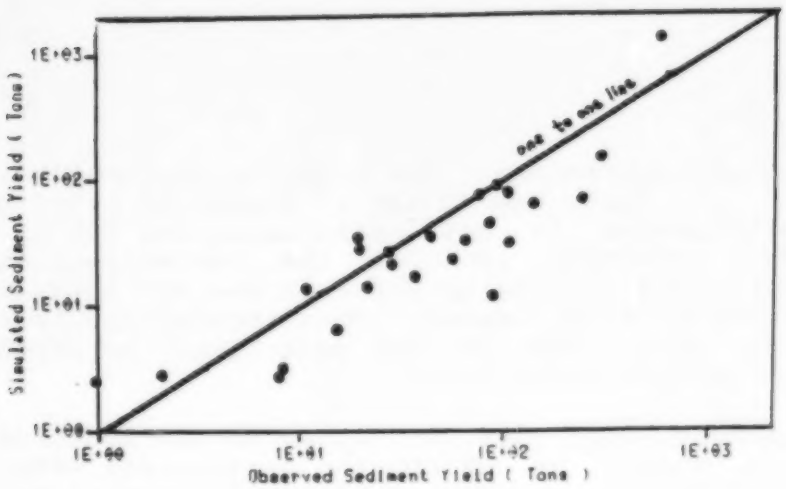

Figure 7. Comparison of Storm Sediment Yields

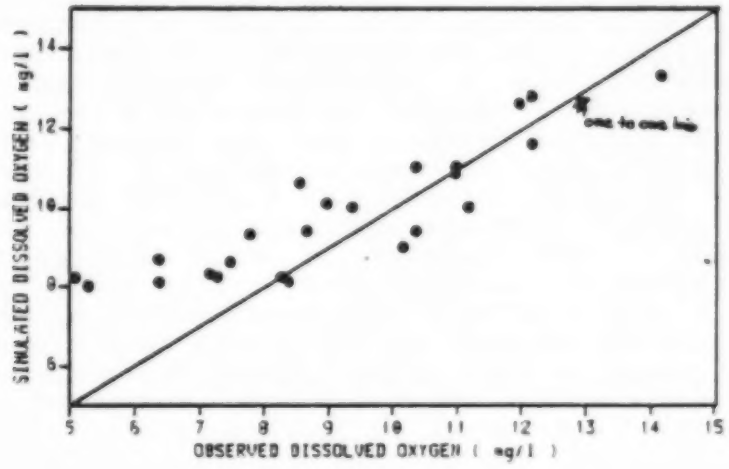

Figure 8. Comparison of Dissolved Oxygen Concentrations

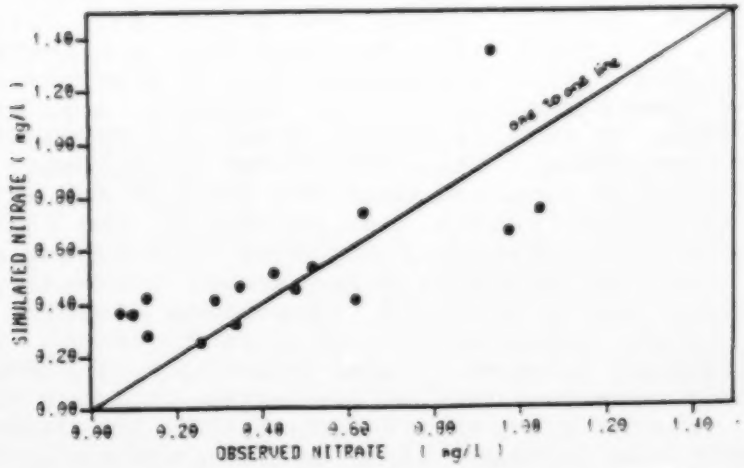

Figure 9. Comparison of Baseflow Nitrate Concentrations

time concentrations. One possible explanation for this is that the uptake of dissolved nitrate by phytoplankton is not being accounted for in the model. Another is that the concentrations of ammonia and nitrate in baseflow are not adequately defined as model inputs. This inclination is also under study and it can most likely be remedied with further calibration.

Remaining work will be focused on the modeling of storm events in which the particulate forms of phosphorus and nitrogen, especially organic nitrogen, are dominant.

Model Projections

As a demonstration of the model's ability to be used as a planning tool, a model projection based on future land use was made. In order to accomplish this in a meaningful manner, one year of meteorological records representing a rather typical or average rainfall year was singled out. The hydrology and sediment components of the model were executed coupled to a network representing the current land use configuration within the watershed. The results of this simulation was subsequently compared to a similar model application with a network representing future land use. The major trends in the future land use are the conversion of most of the forest and nearly all of the agricultural land within the watershed to residential development of varying density. In terms of impervious cover, this translates to an overall increase from 6 percent to 25 percent for the watershed.

The results of this exercise were quite illuminating. First of all, an 18 percent increase in average annual runoff was projected. Virtually all of this can be directly attributed to increased urban stormwater runoff from the future development pattern. In addition, a 21 percent increase in total sediment yield was projected for the watershed. This was rather significant since the planned land use does not include any agricultural usage, which is currently the principal source of sediment. But most interesting of all is the projected average annual increase of 300 percent in scour and streambank erosion. This simulated increase is a direct result of the increased *frequency* and magnitude of stormwater runoff events that is projected to occur because of increased imperviousness within the watershed. Scour and stream bank erosion are particularly sensitive to the attendant increases in velocity that are associated with higher flows.

While these projections must be viewed as preliminary at this writing, they indicate that a four-fold increase in impervious cover can be expected to have a significant impact upon the generation of stormwater runoff within the watershed. In addition, a very major change in the equilibrium between channel processes and the stream banks can be expected, with accelerated stream bank erosion occurring as the result. If this were to occur, the consequences would be detrimental to water quality and to the aquatic and riparian habitat within the watershed.

These preliminary projections clearly demonstrate the need for further analysis of the stormwater impacts associated with proposed development patterns. They also point out the need to investigate the ability of stormwater management practices to contend with projected increases in stormwater volume, sediment yield, and streambank erosion.

REMAINING WORK

The next task will be to complete the water quality calibration. Once this has been accomplished the watershed model will be used to make model projections based upon various land use planning scenarios. The model will also be applied to determine the effectiveness of Best Management Practices (BMPs) in alleviating projected increases in stormwater runoff, nonpoint source pollution, and erosion. And finally, a specific nonpoint source pollution management strategy for the watershed will be developed within the study and presented to the appropriate local officials along with recommendations for implementation.

COMMENTS ON HSPF

Several comments are offered on the use of HPSF to other potential users within the water quality modeling community. First of all, HSPF is a very comprehensive and powerful tool. It was found to be capable of modeling all of the relevant processes at work within a watershed. However, the model itself, model input, and the documentation were not found to be easily understood or oriented toward users. As a result, HSPF proved to be much more complicated than its direct predecessors, and this turned out to be very costly in terms of both staff and data processing. Much more time was devoted to learning how to use and understand the model than originally anticipated. In large part this was attributed to the complexity of the model

and the required input stream, and to what was considered to be inadequate documentation of the processes modeled and the necessary input. As an example of the complexity of the input stream, over 1200 lines of input were required to model the watershed as described with five land use types (including impervious land), seven channel reaches, fourteen subwatersheds, and the full compliment of hydrology, sediment and water quality constituents. This did not include JCL, meteorological data, or other sequential input files. Input of this length becomes somewhat intractable. As a reference for data processing expenses, execution of a one year simulation with an hourly timestep for the watershed application as described above cost $300 (at a rate of $6/minute of cpu). The experience within this study has been that using HSPF is no small undertaking.

SUMMARY

At this point in the study, a credible water resources management tool has been developed for the watershed. This tool, the Piscataway Creek Watershed Model, has been shown to be capable of simulating the principal hydrologic and stormwater runoff processes within the watershed. In addition, the ability of the model to simulate the major processes of the sediment cycle has also been demonstrated. Work is underway to complete calibration of the water quality aspects of the model application. Once this has been accomplished, the simulation of nonpoint source pollution and their impact upon instream water quality and total pollutant loads generated within the watershed will be possible.

The hydrology and sediment components of the watershed model have been applied to assess the change in stormwater runoff volume and sediment load associated with a future land use plan. Significant increases in stormwater and sediment were projected. Additional model projections are planned for further assessment of the magnitude of stormwater and nonpoint pollutant loads. It is anticipated that the usefulness of applying water resources models in the planning process will be demonstrated to local planners and officials.

REFERENCES

Donigian, A.S. and Crawford, N.H. (1976). "Modeling Nonpoint Pollution from the Land Surface", EPA-600/3-76-083, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.

Donigian, A.S. and Davis, H.H. (1978). "User's Manual for Agricultural Runoff Management (ARM) Model", EPA-600/3-78/080, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.

Hartigan, J.P., Quasebarth, T.F. and Southerland, E. (1982). "Use of Continuous Simulation Model Calibration Techniques to Develop Nonpoint Pollution Loading Factors", Proceedings of Stormwater and Water Quality Model Users Group Meeting: March 25-26, 1982, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.

Hydrocomp, Inc. (1977). "Hydrocomp Simulation Programming: Water Quality Simulation Operations Model", Palo Alto, California.

Hydrocomp, Inc. (1980). "User's Manual for Hydrological Simulation Program-Fortran (HSPF)", EPA-600/9-80-015, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.

Northern Virginia Planning District Commission and Virginia Polytechnic Institute and State University (1978). "Occoquan/Four Mile Run Nonpoint Source Correlation Study", report prepared for the Metropolitan Washington Council of Governments, Water Resources Planning Board, Washington, District of Columbia.

Sullivan, M.P., Schueler, T.R. and Reese, D. (1982). "The Piscataway Creek Watershed Model: Documentation of the Hydrologic Calibration and Verification", Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, District of Columbia.